Dynamic Simulation and Analysis of Heating Energy Consumption in a Residential Building

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Abstract: In winter, much of the building energy is used for heating in the north region of China. In this study, the heating energy consumption of a residential building in Tianjin during a heating period was simulated by using the EnergyPlus energy simulation program. The study showed that the heat loss from exterior walls, exterior windows and infiltration took three main parts of the total heat loss. Furthermore, the results of on-site measurement are presented with the conclusion that the EnergyPlus program provides sufficient accuracy for this energy simulation application.

Key words: energy simulation; experimental validation; residential building; energy saving

1. INTRODUCTION

With the rapid development of industrialization and modernization in China, energy consumption is becoming one of the important problems. In China, building energy consumption takes a part of 20.7% of the total energy consumption of the society, from which, heating energy usage in the north region takes a biggest part as 36% [1], and this figure is potentially growing even higher. Since building sector plays a significant role in energy consumption, extensive work should be done to reduce the consumption of building energy.

EnergyPlus is the newest energy simulation program, which is made available by the Lawrence Berkley Laboratory in USA [2]. It was developed in 1995 incorporating the best features of two widely used energy consumption analysis programs: Blast (Building Loads Analysis and System Thermodynamics) and DOE-2[3]. EnergyPlus uses a modular program structure, which makes the code easy to understand and modify. The major improvement in EnergyPlus over previous energy simulation programs is the integrated solution of loads, system, and plant, allowing accurate space temperature predictions [4].

In this paper, EnergyPlus V1.01 was used to simulate the heating energy consumption of an energy saving building in Tianjin during a heating period. The study was intended to analyze the component of heat loss of this building. A validation study was also performed to show the validity of the model used in EnergyPlus.

2. SIMULATION MODEL

The basic of EnergyPlus simulating calculation is the energy balance equations for room air and surface heat transfer [5].

The investigated building at Tianjin was a six-story low rise residential building, with a total of 4,634 m^2 gross floor area. The profile coefficient was 0.2. The projection of the building was rectangle. At each floor there were four apartments with a height of 2.8m. Since there was a seismic joint between apartment two and apartment three, the building was divided as two parts by this seismic joint (the west two apartments were zoon 1, while the east two were zoon 2)， considering the actual heat transfer condition at this spot. The simulation model is illustrated in Fig.1, and the details are showed bellow:

(1) Walls

This room used external insulation in exterior

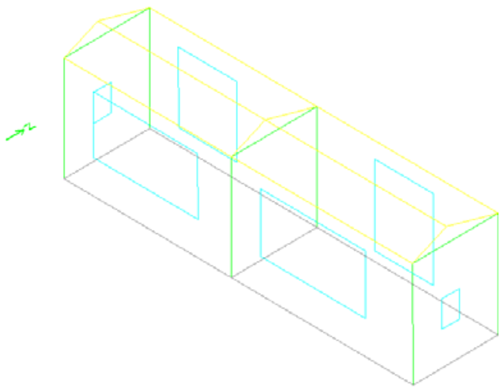

Fig.1 Schematic drawing of the simulation model

walls. The main material of the external insulation and their thermal characteristics are shown in Tab.1.

(2) Windows

The windows faced south were single glazing windows, whose heat transfer coefficient $K \leq 4.7 W/(m^2 \cdot K)$, while, windows faced east, west, north were double pane glass windows with 6mm-thickness air gap between the outside glass and inside glass, whose heat transfer coefficient $K \leq 2.7 W/(m^2 \cdot K)$. According to the Classified Standard of the Infiltration of Building Exterior Windows in China, the air leakage rate of exterior windows in this building was at rank III ($q_L \leq 2.5 m^3 \cdot m^{-1} \cdot h^{-1}$)

(3) Roof

Sloping roof was used in this building, insulated by 150mm-thickness polystyrene board (λ =0.09 $W \cdot m^{-1} \cdot K^{-1}$), whose heat transfer coefficient $K \leq 0.74 W/(m^2 \cdot K)$.

(4) Heat loss by infiltration

In EnergyPlus program, heat loss by infiltration can be calculated by solving the following equation:

$$q_{inf} = q_{L,d} F_{sce} [A + B(T_{zon} - T_{odb}) + Cw + Dw^2] \quad (1)$$

Therein:

q_{inf}—— the simulation result of heat loss by infiltration;

$q_{L,d}$—— the designed value of heat loss by infiltration, in this case was $60 m^3/h$, nearly 0.24ACH(air change per hour);

F_{sce}—— the schedule designed by user (normally seen as 1, only consider of natural factors);

A,B,C,D —— the coefficient of infiltration considering the temperature difference between inside an outside, the outside air velocity and other factors, which in Tianjin is: A=1.35, B=-0.012， C=0.0003， D=0[6];

T_{zon}—— room air temperature;

T_{obd}—— outside temperature;

w—— outside air velocity.

(5) Weather parameters

The simulation period in this case was from November 15th, 2002 to March 14th, 2003. The information of weather is supplied by weather bureau of Tianjin, which contains:

① outside temperature (hourly);

② relative humidity (hourly);

③ wind direction and velocity (hourly);

④ total quantity of solar radiation (hourly).

(6) HVAC system model

In this case, only the building energy usage was simulated, while, the air handling units such as cooling, heating and humidifying appliance were not

Tab.1 The main material and thermal characteristics of the external insulation

Type of insulation	Main material (from outside to inside)	Thickness (mm)	Conductive heat transfer coefficient λ $(W \cdot m^{-1} \cdot K^{-1})$	Heat transfer coefficient K $(W \cdot m^{-2} \cdot K^{-1})$
External insulation	Cement mortar	20	0.930	0.77
	Polystyrene board	40	0.048	
	Solid clay brick	240	0.810	
	Lime mortar	20	0.810	

considered in calculating process. Air supply model was simplified, so the heating load of the room can be calculated by knowing the temperature and humidity of supply air and return air and the calculated supply air volume [2].

(7)The control of room temperature and humidity

In this simulation model, the room temperature was set at 20℃ and the relative humidity was set at 55%, considering the real condition.

3. RESULTS AND DISCUSSION

The daily heating energy consumption of this energy saving building during the whole heating period（from November 15th to March 5th）is showed in Fig.2. The total heating energy consumption during this period added up to 239167kWh, equally to 17.9 W/m^2.

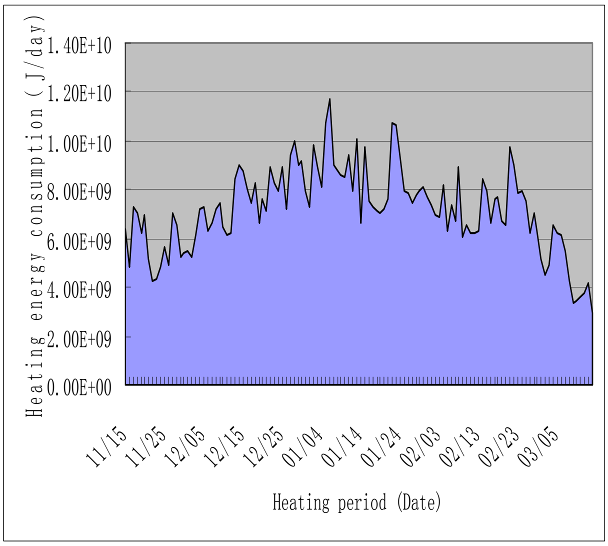

Fig.2 Daily heating energy consumption

A further study showed that the heat loss from exterior walls, exterior windows and infiltration take three main parts of the total heat loss. The heat loss proportion of each part is showed below:

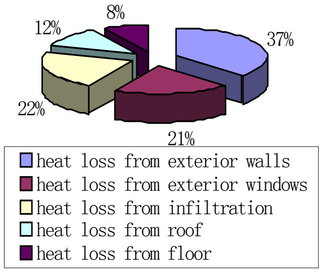

Fig.3 Heat loss composing

4. VALIDATION

An on-site validation measurement was conducted to show the validity of the model used in EnergyPlus, which was focused on an apartment of this building, with a total area of 90m^2, and during a period from November 8th 0:00 am to November 14th 10:00 am, 2002. The simulation result was then compared with the on-site measurement data.

4.1 Outside Dry Bulb Temperature

The comparison of simulation result and measuring result of the outside dry bulb temperature is showed in Fig.4, which shows that although the simulation result is a little in ahead of the measuring result, the value and trend of the two curves are matched very well except for some exceptional values, which suggests that the simulation result is credible.

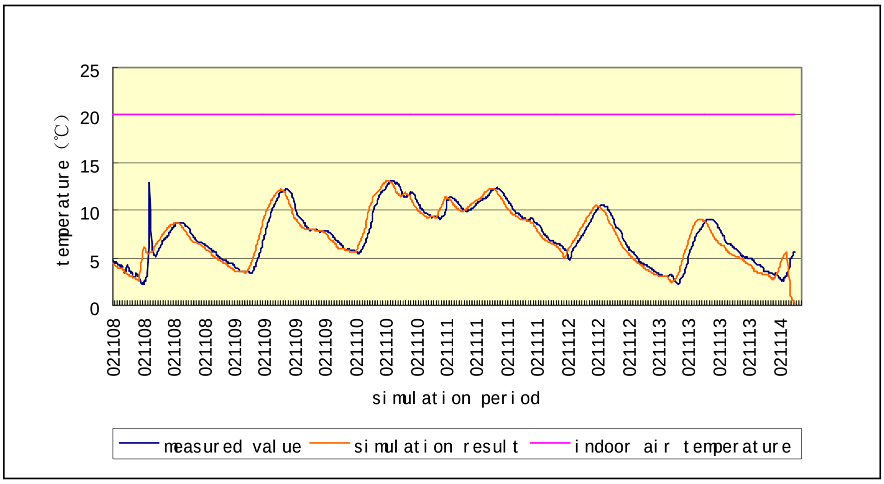

Fig.4 Comparison of simulation result and measuring result of the outside dry glob temperature

4.2 Total Energy Consumption

There was a calorimeter at the heat entrance of each apartment, which can automatically record the quantity of heat supplied to the room during certain period. As the record of the calorimeter showed, during the simulation period, the quantity of heat actually used by this apartment was 289kWh, while, the simulation result was 225kWh. The difference of the two values may be due to the following reasons:

(1) Since the radiant floor heating system was used in this apartment, certain quantity of heat may lost through the hot water running in the pipes beneath the floor to downstairs, and this part of heat loss may up to 15%~20% of the total heat supply by hot water[7]. If this part of heat loss is taken into account, the quantity of heat which the building actually need is less than the recorded value.

(2) Since the structure of this building was simplified in this model, some parts of heat bridge were not fully considered, such as the joints between windows and exterior walls and the like, however, the heat transfer at heat bridge is normally huge. Thus, the simulation result may be lower than the measured value [8].

Considering the above reasons, the accuracy of the simulation result is acceptable.

5. CONCLUSIONS

EnergyPlus can be used to model the dynamic building load according to the principle of conjugate heat transfer, considering the attenuation and delay of the building envelopes. In this case, the heat loss from exterior walls, exterior windows and infiltration take three main parts of the total heat loss. From the comparison of simulation result and the on-site measurement, the validity and accuracy of the model was demonstrated.

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